Computer Science Education and Interdisciplinarity

Cristina-Maria Dabu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68580

Abstract

The world today is characterized through three major elements in the scientific field: the development of classical sciences, the increasingly evolution in the field of computer science and, as result, the emergence of a large number of new border sciences or interdisciplinary and transdisciplinary sciences. In the formation of future specialists, computer science education cannot ignore the reality of a society in which research and technological progress are based primarily on interdisciplinarity and transdisciplinarity. Throughout this chapter, we will analyze the way in which all these elements are evolving in a very closely interdependency one of each other: the evolution of computer science accelerates the development of classical sciences, and the development of classical sciences and computer science generates the emergence and progress of new border sciences and how the educational curricula in computer sciences have to be adapted to this trend. We will present and analyze the ways in which computer science education can be performed in an interdisciplinary and/or transdisciplinary manner at all educational levels. In the same time, we will emphasize the reasons why it is necessary to teach computer science in an interdisciplinary and/or transdisciplinary way and the benefits that teaching strategy brings in the training of future specialists.

Keywords: computer science, education, interdisciplinarity, transdisciplinarity, barriers, emergent science, curricula, creativity, research, skills, development

1. Introduction

The world today is characterized through three major elements in the scientific field: the development of classical sciences, the increasingly evolution in the field of computer science and, as result, the emergence of a large number of new border sciences or interdisciplinary and transdisciplinary sciences.

Interdisciplinary and transdisciplinary research has emerged as a result of the complexity of the world that surrounds us and as a result of the fact that in all fields of scientific research, the complexity of the studied phenomena transcends the borders of a single science.

Another cause that determined the apparition of transdisciplinarity and interdisciplinarity is that the most important discoveries in scientific fields such as life sciences, aerospace sciences, biophysics and other sciences are emerging at the interface between two or more scientific fields.

Even though it is obvious that transdisciplinary and interdisciplinary research leads to spectacular results and that without interdisciplinary and transdisicplinary research current science does not have how to evolve; however, they have been identified a number of barriers that slows interdisciplinary and transdisciplinary approach in scientific research.

A study regarding interdisciplinarity in sciences, conducted by the Academy of Finland [1], highlights a number of barriers of different nature that occur in communication processes and interactions within teams working in interdisciplinary research projects, generating tensions, conflicts or delays in the completion of those projects.

These barriers can be classified into:

- Structural
- Knowledge
- Cultural
- Epistemological
- Methodological
- Psychological
- Reception

We will briefly introduce what each of these barriers represents. A thorough analysis of them is available in Ref. [1].

Structural barriers are related to the organizational structure of the institution or institutions where interdisciplinary research activity occurs: the hierarchy and decision systems, organizational rules, financing sources, influencing how it is carried out the research activity.

Knowledge barriers are generated by the gap of knowledge that specialists in a particular scientific field they have compared to other scientific fields involved in an interdisciplinary research project.

Cultural barriers occur because of problems related to the language used in communication within teams working in multidisciplinary research projects. Each scientific field is characterized by its own specialized terminology, the used terms may sometimes be the same, but in a greater or lesser measure, different in their meanings. As a result, confusion and misunderstandings can arise in the communication on the project, because different terms are used to refer to the same concepts, or similar terms have different meanings from one scientific field to another.

Epistemological barriers are generated by the vision that various scientific fields have regarding the world and by the way in which the various phenomena are perceived in terms of importance by each scientific field separately. It was also found that epistemological barriers depend on the way in which the various scientific fields have evolved over the time.

Methodological barriers are result of the fact that each scientific field is characterized by its own research methodologies in designing, conducting and reporting research.

Psychological barriers arise due to the fact that each scientific researcher involved in an interdisciplinary project is intellectually and emotionally attached to the scientific field to which he/her belongs and in which he/her has invested intellect, time and labor. In addition, the migration of scientific researchers from a research field in a multidisciplinary team, in which they have to interact with other researchers from other scientific fields, characterized by their own culture, especially in the early stage can generate negative emotions.

Reception barriers are specific to those interdisciplinary research project phases in which, in various forms (reports, publications, presentations, applications for funding), the results of interdisciplinary research activity are disclosed to the layman public (appraisers, financiers, civil society), and there are attempts to assess the interdisciplinarity in the project.

We found that similar barriers can also be identified in the case of transdisciplinary scientific research.

The study [1] identifies two main reasons of these barriers:

- The fact that theories and methods belonging to different disciplines are very difficult to integrate in a new common perspective.
- Scientific disciplines are conventions socially constructed that have their own institutional and ideological structures [1].

The Report of the MASIS Expert Group "Challenging Futures of Science in Society—Emerging trends and cutting-edge issues" [2] brings into discussion new concepts regarding science:

- Recontextualization of science
- Strategic research and strategic science
- Governance of scientific institutions
- Reflexive science
- Innovation-oriented research
- Industrialized science
- Structural and cultural transformations regarding science.

Through the concepts introduced and explained in the document, the report highlights new approaches regarding the evolution and philosophy of science. These approaches are generated both by the development sciences (classic sciences and new emerged sciences) and by the complexity of the world we live.

Considering the direction of evolution in scientific research, in order to prepare future professionals who can successfully face the challenges of sciences, education systems must adapt at all levels of education to the interdisciplinary and transdisciplinary trends in scientific research.

Moreover, one of the main objectives of the educational system should be eliminating the barriers identified in interdisciplinary and transdisciplinary research, in order to accelerate the progress of sciences and technology and through them, as result, to accelerate the progress of entire society.

The removal or mitigation of cultural, methodological or knowledge barriers that occur in interdisciplinary and transdisciplinary research can be achieved only through interdisciplinary and transdisciplinary orientation in teaching-learning activities, such that current students, future professionals, will develop from early stage during the years of study those skills that will make them competitive in an interdisciplinary or transdisciplinary scientific research activity.

The report emphasizes the absolute necessity for students to be familiarized with various fields of computer science during their schooling. In order to be an effective approach in favor of students, with long-term beneficial effect on the training of future specialists, familiarizing students with various areas of computer science should be done according on their own leaning skills and interests.

Thus, the discipline computer science should be studied in an interdisciplinary way, correlated with other scientific field (or fields), which constitute the subject of interest for every student.

In the same sense, in another important document, the report of the joint Informatics Europe & ACM Europe Working Group on Informatics Education, we have identified the following objectives concerning computer science education in Europe [3]:

1. Generalization of education in computer literacy and computer science (informatics) at all educational levels.
2. Creating a Europe based on an Informational Society and an informational economy.
3. Introducing digital literacy and computer science in the curriculum for all European countries.
4. Enhancement of The students training in computer science (informatics) so as to make Europe a major player in Information Technology.

The two bodies have developed the following recommendations for educational systems across Europe regarding computer science education [3]:

1. "All students should benefit from education in digital literacy, starting from an early age and mastering the basic concepts by age 12. Digital literacy education should emphasize not only skills, but also the principles and practices of using them effectively and ethically."

2. “All students should benefit from education in informatics as an independent scientific subject, studied both for its intrinsic intellectual and educational value and for its applications to other disciplines”.
3. “A large-scale teacher training program should urgently be started. To bootstrap the process in the short term, creative solutions should be developed involving school teachers paired with experts from academia and industry”.
4. “The definition of informatics curricula should rely on the considerable body of existing work on the topic and specific recommendations of the present report” [3].

As it will be seen in the next chapters, the Romanian educational system integrated in the curricula at all educational levels, computer science education and computer literacy education, correlated with other disciplines included in the school curricula.

2. Computer science in actual science

In the contemporary society, the role of computer science has become and is becoming more and more important in all scientific fields: medicine, pharmacy, economics, education, sociology, physics, chemistry, biochemistry, anthropology, aerospace and others.

The evolution of computer science provides to other scientific research fields powerful instruments for research: high capacity computational systems, able to manage huge databases, powerful and sophisticated calculus algorithms for data analysis and data mining and dedicated software for computer-assisted modeling and simulation. At the same time are being built increasingly sophisticated measuring devices based on highly specialized sensors and biosensors, that incorporate dedicated software packages for automatic processing of collected data. Fall into this category devices used in the study of outer space, devices for measuring biological parameters in medicine, biotechnology, marine research and other similar devices used in physics, chemistry and others.

All these specialized devices, dedicated for gathering and automatic processing of large amounts of data on the one hand, have led to spectacular developments in various scientific fields like medicine, pharmacy, physics, biophysics, chemistry, biochemistry and others, and on the other hand, they have led to the emergence of new sciences, such as exo-oceanography, exo-biology, computing sociology, computing anthropology, computing ecology, computing toxicology and others.

The huge amount of data collected in all scientific fields using specialized devices allow the possibility to use these data in order to elaborate specific prognosis (population health prognosis, population movement prognosis, meteorological and exo-meteorological prognosis, environment evolution prognosis and others). As a result, in almost all fields of research are extensively used experimental models and simulations. This relatively new approach, belonging to the past 25–30 years, has made simulation and modeling to be considered an <<emerging “third leg” of Scientific Investigation>> [4].

Computer science is an extremely abstract, intellectually challenging field, because programming technologies operate with very abstract and codified representations for the surrounding reality. For this reason, especially in the initial stages, interdisciplinary and transdisciplinary research projects involving computer science are faced with certain difficulties, especially concerning the transposition into an abstract representation specific to computer science, the experimental reality belonging to a different scientific field.

These difficulties occurring in research activities constitute another reason for teaching computer science discipline, at all levels of education, in an interdisciplinary manner. Through teaching computer science in an interdisciplinary and transdisciplinary manner, on one hand the future specialist in computer science will have early formed the necessary skills to conduct a dialogue with specialists belonging to other scientific fields, and on the other hand, for specialists from different scientific fields (physics, chemistry, biochemistry, medicine), computer science will no longer be a stranger and abstract area.

Another important issue is that in the era of Big Data, characterized by huge databases in all fields of science (medicine, genetics, sociology, anthropology) collected through most various channels, one of the most challenging scientific work is to identify patterns and consistent elements of knowledge in large databases.

Big Data technology development determined that currently some of of the most increasingly used computing applications and algorithms, used today by researchers in most fields of science, are those dedicated for Data Mining.

In the scientific literature, it is defined the activity of Knowledge Discovery in Databases (KDD) as "the process of identifying valid, novel, potentially useful and ultimately understandable patterns in data" [5]. The most powerful tool used for Knowledge Discovery in Databases, Data Mining represents "a collection of methods of data analysis coming from different fields of computer science, artificial intelligence and statistics" [5].

Taking into account that, as we noted above, computer science is deeply involved in all current sciences, it is considered that "interdisciplinary computer science is becoming the norm" [6].

They are science or scientific results, which could not exist in the absence of computer science. An example of this is the genomic sequencing, a remarkably successful genetics result, which would not be achieved in the absence of tools provided by computer science [6].

In other sciences, like the aerospace sciences or exo-meteorology, they could not exist as scientific fields itself in the absence of computer science, because both in the collection of scientific data and in the processing thereof are being used computer systems and devices coordinated by computer systems (space probes, spatial robots, artificial satellites).

3. Science evolution and emergence

How we have mentioned above, the development of computer science has an huge impact upon the evolution of other science fields (chemistry, biochemistry, physics) and the emergence of new sciences such as Computational Social Science, Synthetic Biology, Quantum

http://dx.doi.org/10.5772/intechopen.68580

Biology, Exo-meteorology, Exo-oceanography, Cliodynamics, Computational Anthropology, Computational Toxicology, Computational Ecology and others.

This is due primarily to the fact that knowledge itself has an interdisciplinary character, and the human brain is trained to process permanently information coming from different scientific areas, and to make extremely rapid correlations between the newly acquired elements of knowledge and the oldest already stored elements of knowledge, belonging to other scientific fields.

Secondly, the extremely rapid evolution of computer science field, as noted in the previous chapters, has provided to the various scientific fields devices and applications able to collect, store and process huge amounts of information. As a result, the amount of scientific knowledge in all areas has grown exponentially and has become much more complex.

Explaining the phenomena based on vast amounts of information collected by devices made available by means of computer science, required the gradual emergence of new interdisciplinary or transdisciplinary scientific fields, some of them impossible to exist in the absence of computer science, and each of them having its own research methodologies, scientific terminology and their own areas of interdisciplinary knowledge.

We will present in the following some such new scientific fields, emerged at the intersection between computer science and other fields of scientific research.

3.1. Computational Anthropology

Computational Anthropology is emerging from a multitude of sciences: Computer Science, Anthropology, Sociology and Geographic Information Science.

The main objective of this new emerged science is the study how patterns of human behavior change over time and space [7].

The scientists in Computational Anthropology are analyzing data collected from social networks and geolocation systems in order to provide new insights regarding the nature of human society [7].

In the last decade, the increasing availability of big data generated by mobile phones and location-based applications has triggered a revolution in the understanding of human mobility patterns. Using specific algorithms for data mining, simulation and prognosis, one can be identified patterns regarding travel around the world, and very important for the health systems from all countries, one can be made forecasts on the spread of diseases and epidemics [7].

In the scientists in Computational Anthropology opinion, "there is considerable interest in looking more closely at human mobility patterns to see just how well it can be predicted and how these predictions might be used in everything from disease control and city planning to traffic forecasting and location-based advertising" [7].

3.2. Computational Ecology

Computational Ecology is another new emerged sciences, based on computer science and ecology.

Computational Ecology is using numerical models and computer simulations in researches regarding dynamics of populations and systems. There are studied tendencies and specificities for a better understanding and prognosis in areas such as fisheries, forestry, agriculture, climate change and evolutionary ecology [8].

Ecosystems are living systems that are formed and evolves in years, decades, hundreds or thousands of years. Consequently, experiments in the classical conception of scientific experiment in order to understand the dynamics and evolution of ecosystems are difficult or even impossible to carry out.

Computing Ecology through powerful research tools provided by mathematical models and computer aided simulations, software systems able to analyze large amounts of data gathered in situ, enables understanding of phenomena and processes occurring and enables elaborating predictions regarding the evolution of ecosystems.

This newly emerged science is of great importance in the heavily industrialized contemporary society, where the ecological disasters caused by various agents have become very common.

3.3. Computational Toxicology

Computational Toxicology is another new emerged science, correlated with computational ecology and environmental protection.

It was officially mentioned for the first time in September 2009 when the National Research Council Committee on Use of Emerging Science for Environmental Health Decisions held a public meetings titled "Computational Toxicology: From Data to Analyses to Applications" [9].

Computational Toxicology offers the opportunity to study and forecast, based on mathematical models and computer-aided simulation, the harmful effects that various toxic pollutants or sources may have on the environment, humans and animals.

The new emerged science brings substantial scientific contribution in a field in which experimental research are extremely harmful for the environment and humans. For this reason, experiments have to be replaced with computer-assisted simulations based on mathematical models, without danger for humans, animals and environment.

3.4. Exo-Meteorology

Exo-meteorology is a new emerged scientific and research field which is studying the meteorological phenomena that take place on other planets existing our solar system [10].

Field of research could not exist in the absence of computer science. Computerized systems are needed both in the collection and storage of data, as well as for their processing and interpretation and for the elaboration of forecasts.

Forecasts elaborated by this newly emerging science are important in planning space missions [11].

4. Computer science education in curricula

As we have seen in the previous chapters, in the context of actual science and society evolution, the goal of computer science education is to prepare actual students, future specialists, to work and think at the intersection between computer science and other scientific fields.

Considering that the in almost all scientific fields are used computer-assisted modeling and simulations, it is essential for future researchers to be familiar with algorithmic thinking and computer science. In addition, the barriers that arise during interdisciplinary and transdisicplinary research activities, mentioned in previous chapters, represent another important reason for approaching an interdisciplinary manner in teaching computer science, using examples and applications from other disciplines or from the world around us.

In the Romanian educational system, at all levels of education, curricula contain computer science education with multiple goals:

- To familiarize the student as computer user as future specialist in a particular scientific branch.
- Development of specific algorithmic thinking skills, useful for a future specialist in any scientific field.
- Development of programming skills for creating dedicated software systems in other scientific fields (biology, chemistry, physics).

In order to attain these objectives in teaching computer science, in the Romanian education, one has been made remarkable progress in the last 17 years, both in terms of technical endowment and in terms of improving the school curricula:

- Schools, high schools and universities were equipped with computer networks, connected to the internet.
- One was developed educational software packages for almost all subjects in the curricula.
- One has been made available for students' online platforms for training in computer science for Olympiads in informatics and other informatics competitions.
- One has been developed support materials and training programs for teachers.
- Many programs or projects aimed to promote new technologies in education and supporting computer-assisted learning (eLearning).

The Romanian education curricula take into consideration more categories of competencies:

- European key competencies
- Competencies established by the Romanian Education Law

At the fifth grade level, the European key competencies that need to be developed throughout the course information and communication technology are:

- Digital competences
- Mathematical competence and basic competences in science and technology [12].

Consistent with these European key competencies, the competencies established by the Education Law in Romania are as follows:

- Digital skills to use information technology as a tool for learning and knowledge
- Basic skills in mathematics, science and technology
- Social and civic competences
- Competence of learning to learn [12].

To ensure the interdisciplinary study of computer science, the curriculum recommends: "For the good development classes and curriculum implementation, to correlate is recommended teaching activities of other subjects studied the content" [12].

The main topics of the computer science curricula (Computer Literacy) at the fifth grade are:

- Basic computer hardware
- Windows
- Paint
- Microsoft Word
- Powerpoint

At high school level, the curricula provide differentiated study of computer science, according to the high school profile:

- Humanities
- Real (science)
- Computer science
- Arts and crafts

In Romania, the school curricula for computer science education provide both teaching hours and laboratory hours.

For high school, profile humanities, computer science education, consist in Computer Literacy (general) and Desktop Publishing.

On the other hand, for high school profiles real (science) and computer science, there are hours of algorithms, computer literacy, computer programming course in C++ or Pascal and laboratory courses.

During the programming courses (C++ or Pascal), there are taught concepts like:

- Data types and variables
- Operators
- Simple instructions

- Control structures
- Pointers
- Functions
- Lists, stacks and queues
- Algorithms for searching and sorting

During the laboratory courses, students develop their own computer programs applying concepts learned in the classroom.

Involving students during the laboratory classes in interdisciplinary projects like:

- Software system for the study of geography
- Software system for the study of foreign languages with computer
- System Software for the modeling of some physical phenomena
- Software system for studying cell division
- Software system for mathematics study
- Software system for chemistry study

stimulates the development of interdisciplinary skills of the students.

Working organized in teams on projects such as those mentioned above, students are challenged to develop their critical thinking, analytical skills and abilities:

- They must know and implement concepts learned during the hours of Computer Science.
- They need to know at a sufficiently high level concepts belonging to the scientific fields for which they develop the software system.
- They must select which concepts will be introduced in the software system they build.
- They have to organize logically and easily accessible the informations within the software system.

The students have to analyze and determine what information from the selected scientific field that will take in the information system (theoretical concepts, exercises, tests for assessing knowledge).

They should consider how they will present the information in the software system in order to be easily accessible for the final user.

Students have to design and implement interfaces between the user and the computer system, students must show creativity and develop their creativity, and they have to know concepts regarding ergonomics of man-machine interfaces.

They design and implement computer-assisted exercises, quizzes and tests and evaluation algorithms for the verification of the acquired knowledge.

Through these projects, students are challenged to research and development of interdisciplinary and transdisciplinary knowledge of various fields merging computer science and other school disciplines, depending on the project and on students own preferences.

In addition, the teamwork activity forces them to develop their communication skills, collegiality, adaptability and other skills needed for teamwork, skills required also as future professionals who will need to integrate into a team of interdisciplinary and/or transdisciplinary research.

Under this manner, teaching computer science is done in an interdisciplinary and transdisciplinary way, which encourages students not only to study strictly the discipline of computer science but also encourages them to expand their knowledge in other scientific fields in order to develop their software projects during the laboratory hours.

Another extremely challenging exercise for students, which we use in teaching the chapter regarding computer structure (computer hardware), is to identify the various components of a computer in other devices that run based on computer programs and computational systems:

- Devices to monitoring patients in hospitals
- Fuel pump from gas stations
- Washing machine
- Mobile phones
- Other similar systems

Students are encouraged to identify for each case what would be the input unit, the output unit, whether the device is equipped with external memory or not and what would be their role and what would be the role of command and control unit. Such students are encouraged to think about a computer device in the context of another domain (medical, telecommunication, oil and appliances), helping them to develop their interdisciplinary and transdisciplinary thinking ability.

We have used these methods for teaching computer science in many schools throughout time and every time which have given very good results. Students have very good results informatics Olympiads and competitions, and some of them, who have followed careers in computer science, have integrated very well on the job.

At academic level, interdisciplinarity and transdisciplinarity of computer science education are reflected in the large offer of masters or doctoral programs and academic courses that universities offer their students on various interdisciplinary or transdisciplinary areas:

- Computational Biology,
- Computational Biochemistry
- Computational Bioengineering
- Computational Geometry

http://dx.doi.org/10.5772/intechopen.68580

- Computational Linguistics
- Computational Physics
- Computational Ecology
- Computational Economics and others.

All these <<computational X>> [13] programs and courses at academic level are in close correlation with the new emerging scientific and research fields, in order to train specialists for the respective fields.

In addition, these interdisciplinary programs or courses, based on computer science, contribute significantly to removing some of the barriers involved in interdisciplinary research, we have mentioned in the previous chapters. Students trained in two or more different scientific fields, as future professionals working on interdisciplinary or transdisciplinary research projects could more easily overcome with the difficulties raised by cultural barriers, methodological barriers or knowledge barriers.

5. Conclusions

Without exhausting the subject, throughout chapter, we have presented that the reasons that have lead to interdisciplinary and transdisciplinary research and the barriers that appear in interdisciplinary and transdisciplinary research activity.

Our society is in constant evolution, scientific and technical and educational program must follow this evolution in order to prepare future specialists to the standards required by the society.

Evolution of computer science has a major impact in the development of science, not only by the contribution to getting some spectacular scientific results already established in areas of science but also by contributing to the emergence of new scientific fields. There have been summarized in this regard several new emerged scientific fields whose research activities have major impact in human society: Computational Ecology, Computational Toxicology, Computational Anthropology.

Education in the field of computer science can be done both as a self-contained discipline, but more important is the study of computer science in an interdisciplinary manner.

Teaching computer science in interdisciplinary and/or transdisciplinary manner, by engaging students in interdisciplinary projects or offering them interdisciplinary and/or transdisciplinary courses and specialization programs, as we have shown in the chapter, will help them to develop a series of skills needed for future interdisciplinary scientific research.

Also engaging students during computer science hours to identify ways, in which computer systems are used in the management of various processes in the world around us, contribute to help the students to develop specific skills regarding analysis and identification of systems.

Systems analysis and identification are concepts belonging to systems theory and are currently applied in most fields of scientific research. They are used for many years in scientific research concepts such as biochemical systems, biological systems, ecological systems and others.

All these concepts are interdisciplinary concepts which correlate computer science and systems theory with other scientific fields and are crucial especially in computer aided modeling and simulation. It is therefore important that during the classes of computer science, students become familiar from early stages with systemic thinking, which is essential in building software applications dedicated to other scientific fields.

Interdisciplinary and transdisciplinary approach stimulates scientific curiosity, an essential feature for a future scientific researcher. Scientific curiosity is typical of human nature, which always, from the ancient times, sought to understand and explain phenomena that occur in the natural world and modern education systems should aim to encourage and develop this scientific curiosity.

School systems from everywhere, through educational curricula content and through educational strategies, should stimulate and develop scientific curiosity of students in light of forming future specialists.

Author details

Cristina-Maria Dabu

Address all correspondence to: cmdabu@yahoo.com

Romanian Committee of History and Philosophy of Science and Technology—Romanian Academy, Bucharest, Romania

References

[1] Bruun H, Hukkinen J, Huutoniemi K, Thomson Klein J. Promoting Interdisciplinary Research: The case of the Academy of Finland. http://www.aka.fi/globalassets/awanhat/documents/tiedostot/julkaisut/8_05-promoting-interdisciplinary-research_-the-case-of-the-academy-of-finland.pdf [Accessed 17.01.2017]

[2] European Commission Challenging Futures of Science in Society-Emerging trends and cutting-edge issues, Report of the MASIS Expert Group setup by the European Commission, 2009, https://ec.europa.eu/research/science-society/document_library/pdf_06/the-masis-report_en.pdf [Accessed 21.12.2017]

[3] Informatics education: Europe cannot afford to miss the boat. Report of the joint Informatics Europe & ACM Europe Working Group on Informatics Education, April

2013, http://www.informatics-europe.org/images/documents/informatics-education-acm-ie.pdf [Accessed 22.01.2017]

[4] Bradly Alicea, Scientific simulation and modeling, https://msu.edu/~aliceabr/sci_sim_class.pdf [Accessed 22.01.2017]

[5] Marco Remondino, Gianluca Correndo, Data Mining Applied to Agent Based Simulation, 2005. http://eprints.soton.ac.uk/267933/1/or-14.pdf [Accessed 22.01.2017]

[6] Computing Education Computing Research Association Innovative Approaches to Computing Education, http://cra.org/wp-content/uploads/2015/08/ComputingEducation-Final-Report.pdf [Last visited 22.01.2017]

[7] https://www.technologyreview.com/s/528216/the-emerging-science-of-computational-anthropology/ [Accessed 17.01.2017]

[8] http://rsfs.royalsocietypublishing.org/content/2/2/241 [Accessed 10.01.2017]

[9] http://nas-sites.org/emergingscience/files/2011/05/newsletter4_comptox-rev.pdf [Accessed 21.12.2017]

[10] http://io9.gizmodo.com/5987296/11-emerging-scientific-fields-that-everyone-should-know-about [Accessed 17.02.2017]

[11] http://www.solaciumcorp.com/what-we-do/air-space/exo-meteorology/[Accessed17.02.2017]

[12] http://www.ls-infomat.ro/user/content/1731programa_tic_cls_a_v_a.pdf [Accessed 10.01.2017]

[13] Joint Task Force on Computing Curricula, Association for Computing Machinery (ACM) and IEEE Computer Society. Computer Science Curricula 2013: Curriculum Guidelines for Undergraduate Degree Programs in Computer Science. ACM, 2013